DOCUMENT RESUME

ED 156 903 CE 017 290

AUTHOR	Gant, Charles R.
TITLE	Economics of On-the-Job Training: Annotated Bibliography and Literature Review. Final Report for Period October 1974-November 1976.
INSTITUTION	Air Force Human Resources Lab., Lowry AFB, Colo. Technical Training Div.
SPONS AGENCY	Air Force Human Resources Lab., Brooks AFB, Texas.
REPORT NO	AFHRL-TR-76-83
PUB DATE	Dec 77
NOTE	35p.; Quoted matter in this document may not reproduce well due to small print
EDRS PRICE	MF-$0.83 HC-$2.06 Plus Postage.
DESCRIPTORS	*Annotated Bibliographies; *Cost Effectiveness; *Economic Research; Educational Accountability; *Educational Economics; Human Capital; *Literature Reviews; *On the Job Training; Productivity; Socioeconomic Background; *Systems Analysis; Welfare

ABSTRACT

To aid in the development and validation of a cost analytic model for Air Force on-the-job training (OJT), this report reviews the literature on the economics of education and training through mid-1976 inclusively. The first two of the four parts in the document provide narrative discussions of the literature, and the last two contain the bibliographic lists. In section 1 six studies on the costs of OJT are analyzed and evaluated, while in section 2 economics literature of a more general nature is discussed, focusing on three background areas: welfare theory, human capital, and joint production (two or more outputs from one production process). Section 3 is an annotated bibliography of eighty-eight items; the annotations, which are only descriptive, not evaluative, vary in length from one sentence to half a page. The last section consisting of four and one-half pages is an unannotated list of additional references. The items chosen in the two sections encompass journal articles, reports, monographic studies, and texts. Where applicable, Rand report numbers and ERIC document numbers are given. (ELG)

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AFHRL-TR-76-83

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AIR FORCE HUMAN RESOURCES LABORATORY

ECONOMICS OF ON-THE-JOB TRAINING:
ANNOTATED BIBLIOGRAPHY AND LITERATURE REVIEW

By
Charles R. Gant

TECHNICAL TRAINING DIVISION
Lowry Air Force Base, Colorado 80230

December 1977
Final Report for Period October 1974 – November 1976

Approved for public release; distribution unlimited.

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This final report was submitted by Technical Training Division, Air Force Human Resources Laboratory, Lowry Air Force Base, Colorado 80230, under project 1121, with HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235.

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Technical Training Division

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFHRL-TR-76-83	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ECONOMICS OF ON-THE-JOB TRAINING: ANNOTATED BIBLIOGRAPHY AND LITERATURE REVIEW		5. TYPE OF REPORT & PERIOD COVERED Final October 1974 – November 1976
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Charles R. Gant		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Technical Training Division Air Force Human Resources Laboratory Lowry Air Force Base, Colorado 80230		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62205F 11210504
11. CONTROLLING OFFICE NAME AND ADDRESS HQ Air Force Human Resources Laboratory (AFSC) Brooks Air Force Base, Texas 78235		12. REPORT DATE December 1977
		13. NUMBER OF PAGES 36
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

cost-benefit analysis
economics of education and training
human capital
joint production
on-the-job training (OJT)
public enterprise
resident training
systems analysis
welfare theory

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this study was to present a thorough review of the literature on the economics of on-the-job (OJT) training. The information contained herein is to be used in developing a cost analytic model for Air Force OJT, under a follow-on contractor work unit. The most relevant literature is reviewed in depth, and background research areas are examined. An extensive annotated bibliography, plus numerous additional references, are included.

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CE 017 290

PREFACE

This research was completed under project 1121, Technical Training Technology, Dr. Marty Rockway, Project Scientist; task 012105, Applications of Systems Analysis to Technical Training Development, Dr. Ron Burkett, Task Scientist; and work unit 11210504, Mr. Charles Gant, Project Scientist. The report covers research performed between October 1974 and November 1976.

The author wishes to express appreciation to Dr. Ron Burkett, Ms. Linda Waddelow, Amn William Dimitroff, Ms. Cecelia Higgins, Maj Brian Waters, and Ms. Gerry Williams, for their help in editing and preparing the draft manuscript.

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ECONOMICS OF ON-THE-JOB TRAINING: ANNOTATED BIBLIOGRAPHY AND LITERATURE REVIEW

I. INTRODUCTION

The project's objective was to thoroughly review the literature on analytic techniques of on-the-job training, inclusive through mid-1976. In 1974, Hq USAF requested a cost analysis of on-the-job training (OJT) in the Air Force. The results of the present report are to be used in the development and validation of a cost analytic model for Air Force OJT, under a follow-on contractor work unit.

A review of direct and indirect methods of cost analysis related to OJT was made to assure coverage of all relevant materials. Five major areas were examined. They were:

1. Theoretical economic issues.
2. Cost analysis, cost-benefit analysis, and systems analysis.
3. Models, simulations, and games.
4. The all-volunteer force.
5. The economics of education and training.

The primary focus of this review was on the last area.

This report is organized into four sections: First is a narrative section which details the literature directly impacting this study. The second section takes broader aim, looking at the theoretical areas which directly affect the study. This section also addresses analytical techniques related to the objective of this work unit. Section 3 of this report provides an annotated bibliography on all the literature reviewed during this effort. Section 4 contains a listing of additional references.

II. THE LITERATURE ON THE COSTS OF OJT

To date, the literature concerning OJT and its costs has been sparse. Theoretical treatment of education and its efficiency began over two hundred years ago with Adam Smith's *Wealth of Nations*. These expositions were called "studies of human capital." However, this term is of relatively recent origin. In 1966, Kiker published a review of the history of human capital, including its theory and practice, up through Walsh in the 1930s. Of particular concern to the present review is that portion of literature dealing with manpower programs and their costs.

Studies dealing with manpower programs and their costs have usually defined relevant cost as the cost of the program to the individual. In general, this approach has not been useful in the present context of this review. The total "social cost" of a program was of interest; not just the cost to the individual or company. Examples of such studies abound in the literature, and for this reason, an exhaustive list is not provided in the annotated bibliography; however, a representative sample has been included.

Two approaches have been taken to determine relevant costs. The first approach is to take a company's training program, tabulating the company's cost in salaries (either of the employees in training or of those temporarily hired to replace them while training is in process), tuition/fees, books, plus other direct costs. This tabulation is used to determine overall program costs. Returns have usually been calculated on the basis of increased productivity from the trainees, measured in terms of salaries paid to similarly trained employees, from which the salaries of the trainees are subtracted after training. If the difference (return) is greater than the costs, over the long run, the program is termed a success. The second approach, which might be called the individual approach, calculates the costs to the individual incurred by entering a training program, completing it, and then receiving a higher salary in the future. Individual costs

(foregone income or leisure) are subtracted from the increase in salary expected as a result of his increased human capital. As in the previous approach, if the index is positive, then the program is termed a success. The difficulty of these two approaches is that neither internalizes all the costs/returns of the program. For present purposes, the first approach may be more appropriate; however, military personnel are not replaced or eliminated during training. They are kept at their jobs, and this impacts duty time and supervisory time during training. The real difference is that the aforementioned approaches deal with formal, "resident" training programs rather than on-the-job training.

The literature of education economics has been similar to the literature of OJT. However, greater emphasis has been placed on the examination of costs and returns to the individual. This concept has been used for the examination and evaluation of economic issues ranging from growth to individual planning, with growth studies being analogous to the institutional approach previously discussed, and individual investment studies analogous to the individual approach to OJT. Bowman (1969) and the UNESCO (1962), show the importance of fitting education into the growth schedules of developing economies.

The material of central interest to those studying the economics of OJT probably began with the book by Becker (1964). Although its title includes a reference to education in general, there was a specific treatment of on-the-job training. Studies by Mincer (1962) and others clarified the theoretical background, while military analysts followed with studies of their respective service training programs. Analysis of military OJT was performed by Arzigian (1967) for the Navy, and Dunham (1972) and Gay and Nelson (1974) for the Air Force.

Becker (1964) divided OJT into two types, general and specific. General training prepared a person for an occupation (he used machinist training as an example). General training was usually paid for by the trainee, largely because the investing firm had no guarantee that it would receive any return from its investment. Usually, the trainee paid in the form of decreased wages over a period of time. Specific training was training considered to be at least partially useful to the specific operations or processes of the employer. The military was cited as providing many examples of specific OJT; such as that for astronauts, fighter pilots, and missilemen. This list could also include infantrymen, mortarmen, bomb loaders, and weapon mechanics. The extensive specific OJT in the military has had few secondary effects in the form of social benefits, while general training has had greater implications to the civilian economy. These general training benefits stem from the provision of militarily trained manpower such as warehousemen, cooks, and clerks who may continue working in these jobs after they have been discharged from the military.

General-trained civilians are paid less during their apprenticeship than afterwards in an attempt by the firm to get them to pay for their training. Specific-trained individuals are paid their full wages (as the employer reaps most of the benefit). It could be said that the military student in specific training should be paid more during training than the individual in general training is paid. This, however, has not been the case. In the military, all personnel have been paid a uniform wage. The military has provided proficiency pay as a means to pay more over the long run to an individual in specific training. Such pay was given on the basis of occupational field in the Air Force. Thus, while civilians have benefited from general training in delayed form, military personnel have been paid for specific training in delayed form. This has allowed military individuals, who receive universally valuable training, to avoid the payment (in wage differences relative to their peers) of the investment costs paid for training by their civilian counterparts. However, with respect to the military the results are similar to the end result in a civilian economy:

> Rational firms pay generally trained employees the same wage and specifically trained employees a higher wage than they could get elsewhere. . . firms are not too concerned about the turnover of employees with general training and have no incentive to offer them a premium above wages elsewhere because the cost of such training is borne entirely by the employees. Firms are concerned with the turnover of employees with specific training and a premium is offered to reduce their turnover because firms pay part of their training costs (Becker, 1964, p. 24).

So, the Air Force approach of paying proficiency pay incentives to its specific-trained personnel can work economically when properly used.

Mincer (1962) considered what should be included as the cost of performing OJT. He asked what part of a firm's outlay should be added to foregone worker income to define the total cost of OJT. His answer was "none," if all of the firm's outlay was covered by reduced worker income. He also noted that "Adding a firm's outlays in this case would constitute double counting" (Mincer, p. 52). He added that when workers did not shoulder the whole cost in reduced wages, the firm expected to recoup the difference later in the form of a disparity between wage and marginal product of the worker. He concluded that, "It is impossible to estimate how large a fraction of firm outlays are costs borne by the firm" (Mincer, p. 52).

Mincer's approach to estimating the costs of OJT in terms of foregone income would be to compare a group of individuals who engaged in OJT with a similar group that did not. He would expect that the age/earnings profile for the first group would be higher than that for the second, the difference being reflected in the returns to OJT at later stages and the costs at earlier stages. He stated that such a comparison is, unfortunately, empirically impossible due to the inability to appropriately classify workers. He cited an exception provided by the Consumer Union Panel from a sample taken in 1959, which indicated that the larger the difference at the early stage, the greater the difference later; i.e., that a greater investment yielded a greater return.

Since he did not have exactly the data needed, he used an alternative method to estimate the costs and returns of OJT. He compared the income experiences of college graduates with those of high school graduates.

He assumed that opportunity costs of college attendance were approximated by the income of comparable groups to the college students who worked instead of attending college. There were some biases in the procedure which Mincer enumerated, among which were the problems of using cross-sectional data with secular changes in the earnings streams, and the probable self-selection of nonhigh school graduates with respect to race, occupation, and IQ. Farm workers and minorities were highly represented in the early dropouts, and their prospects for income and return to human capital investment were probably different from white, nonfarm dropouts.

In estimating training costs, Mincer noted that the figures he worked with included only firms which had formal training programs. Therefore the estimate of total costs "misses all costs incurred in informal training, which is the typical situation: only 16.2 percent of firms in New Jersey had formal training programs" (Mincer, 1962, p. 63). The military equivalent of these formal programs is called the technical school, which amounts to a condensed form of specific training done at a military technical training center. Military training was included in Mincer's total, and it was estimated at $1.6 billion in 1959. His data included military schools and training programs, but excluded basic depreciation of equipment (Mincer, 1962, p. 63). Blitz (noted by Mincer) estimated this data, which also appeared to have excluded most forms of OJT. The only part of OJT included in that aggregation was the creation and distribution of career development course (CDC) materials, as those were the only relevant data readily available at the time of Mincer's paper.

Arzigian (1967) made an attempt to analyze the costs of OJT for the Navy. Some very interesting simplifying assumptions were made which may be feasible for future studies in the same area:

1. The length of time it took to attain journeyman level (equivalent to the 5-skill level in the USAF) was dependent on the specialty's membership in one of four categories distinguished by type of employment (function) of the trainee.

2. Each category had a different time span between exit from the recruitment/basic training phase and attainment of journeyman levels, ranging from 12 to 36 months, depending on the complexity of the specialty.

3. Attainment of this level implied a capability to do work in the specialty without close supervision.

4. A man's effectiveness increased linearly from the time of his exit from basic training through the completion of OJT to journeyman level.

This final assumption implied that by the end of a formal school, the person's value had increased without cost to the OJT system (all costs having been absorbed by the formal course) and that this level of effectiveness was the one at which he started his OJT. Further, this implied that this rate of learning continues essentially forever (at least through the journeyman level). A further assumption was that the supervisor spent five percent of his time with the trainee and was of the E6/E7 rank.

While none of these assumptions would likely yield an exact and accurate estimator of cost at any one time, in the aggregate, each was probably a fair estimate. For instance, it was unlikely that the incremental utility of the trainee increased linearly. It was more likely that there were decreasing incremental returns. By the same token, it was likely that learning took place less rapidly on the job than it did in school. The sum effect of these two nonlinear functions might be approximated by the straight line function Arzigian posited. Note Figure 1, area A, under the straight line. This represents a hypothetical recent graduate's utility, starting with his critical low productivity in terms of the mission and his rapid adjustment and increasing utility, which finally intersects the projected utility sometime after his arrival. Area B represents the excess of actual utility over estimated utility through the attainment of journeyman status. To some extent, area A offsets area B and tends to make f(x) a reasonable approximation of u(x). The same analysis applies to the use of a constant five percent time investment by the supervisor, with the early investment heavier, and the late investment lighter than the constant rate.

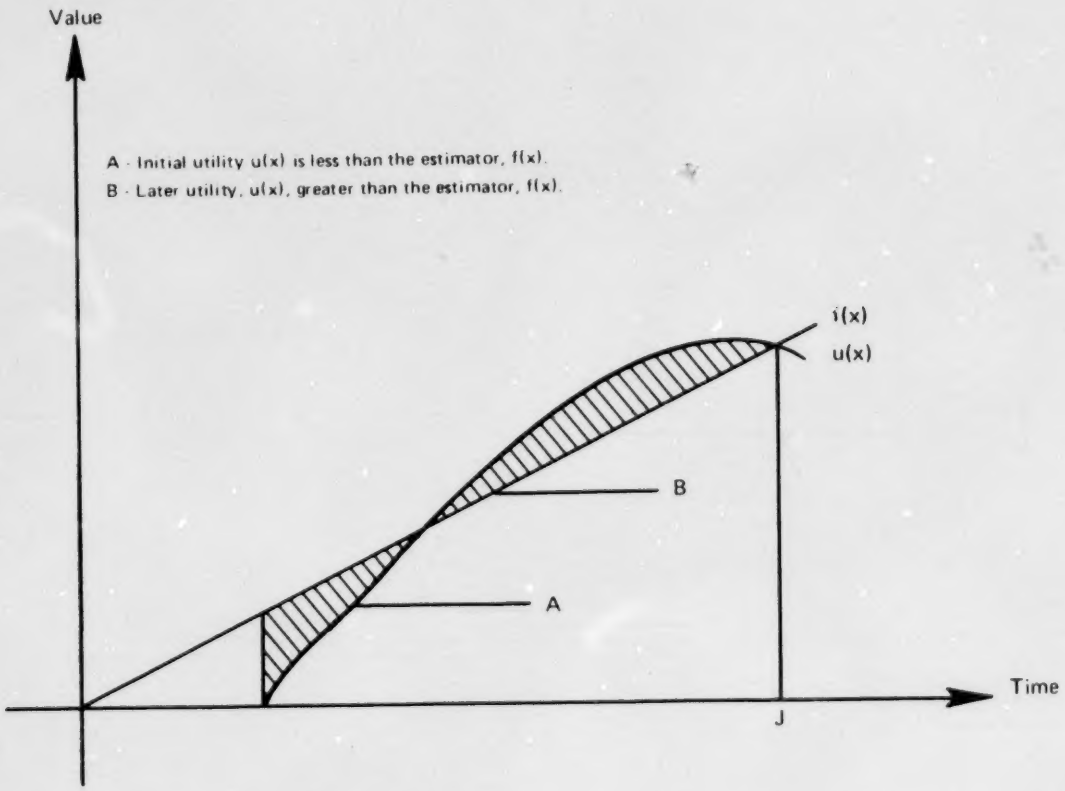

Figure 1. **Technical utility and its estimator. (from Arzigian, 1967)**

For application to the Air Force, this analysis leads to difficulty in determining the length of time it takes to reach the journeyman level. While Arzigian divided the Navy personnel into four categories (Technician, Mechanic, Operations, Support) with different times to proficiency, from 12 to 36 months, there is no comparable alignment for USAF personnel. The four categories used to separate Air Force career fields would have internally divergent levels of difficulty, and so are not susceptible to easy generalization.

Carpenter (1970) described the Air Force training program, its use of skill levels and various training methods, and the problem of matching training needs to training programs. Occupational surveys and their use in designing curricula were included in the analysis. Questions of the cost of designing courses with trainee attributes in mind arose when deciding whether to include subjects in a technical school or in OJT and where neither may be appropriate.

> The Air Force is at a serious disadvantage in approaching this question because the costs of OJT and other training in a job setting are not known. In fact, it may well be that the bulk of training costs are hidden in the operating budgets of the major commands, with the results that the greatest effort to achieve training efficiency is focused on Air Training Command (ATC) merely because its cost is identifiable as training cost (Carpenter, 1970, p. 19).

> Dollar cost should not be the sole determinant of training mode, however. . . .in these (hazardous training) cases the question of dollar cost becomes that of determining how to simulate the amount of realism needed for minimum dollar cost (Carpenter, 1970, p. 20).

The actual cost of doing dangerous training on the job is high when the costs of life, property, and personal service are explicitly included. Lowering the risks associated with job performance has a substantial history of economic rather than humanitarian causes, and this case is no different. The government is responsible for the care of injured personnel, and it is better business to pay to prevent accidents than to pay to heal the injured. Carpenter (1970, p. 20) also asserted that high-level supervisors were not rewarded or rated for their performance as trainers. On the contrary, their performance in maintaining and improving the proficiency of their subordinates is very definitely a part of their assigned duties. It is very apparent that their primary job, completing their mission, is quite dependent upon the skill of their workers.

Regarding the generality of instruction and its applicability to the same tasks in changing settings, Carpenter said,

> Perhaps the best way to develop the trainee's ability to generalize without overgeneralizing would be to give him opportunities to perform the same task under widely varying conditions, and this can be accomplished most readily in formal training. For example, different commands may have different requirements for documentation, different amounts of time may be allotted to the task, or different mixes of skills may be used in carrying it out (p. 28).

From the standpoint of efficiency, however, it appears that there is a decreasing return on investment as trainees are tailor-made for specific jobs. When the additional burden of keeping the school current has been added to the expense of tailoring instruction, the increased productivity of graduates has failed to justify the costs of the tailored program. A graduate's familiarization time at his first assignment might be slightly reduced if the precise conditions to be met were included in alternative formats used in the school. Otherwise, the only training used on the job is the specific skill (manual or otherwise) learned plus some degree of job familiarity resulting from the multiple training. It is likely that the repeated instruction proposed (typically hands-on training) is most efficiently done on-the-job, where a one-to-one correspondence exists between what is taught and what is needed. There should be no loss of efficiency if there is a direct correspondence between trainee performance in school and what the trainee is expected to perform on the job. However, the one-to-one instructor/student ratio which appears to be inefficient on the job would have to be duplicated in the classroom if good results were to be obtained.

The next point made was that training should be aimed toward performance of job-related tasks rather than general knowledge. Carpenter suggested limiting the delivery of general background information and theory to that required to summarize general principles and to teach the jargon of the trade. She presented the view that training may be too task-oriented to provide the general understanding of

"principles of job performance" (rules of thumb) used by journeymen. She observed that, "These are often quite unrelated to the theory of mechanics and other subjects that pass as 'fundamentals' in much of formal training." (Carpenter, 1970, p. 22). In other words, presenting inappropriate background information is no better, and probably worse, than presenting none at all.

The main problem in matching training programs to the needs of the Air Force was that there were no mechanisms for automatic adjustment of course content and instructional methods of changing student populations and training requirements. According to Carpenter, "Usually, however, until the mismatches become too severe, individual training programs slowly drift toward less-and-less-efficient matches with the job requirements" (Carpenter, 1970, p. 23).

The report concluded with a section of future directions for research. Areas of needed research included job descriptions, measurement of trainee attributes, determination of course content, whether training should be done in a resident school or on the job, and possible institutional changes for enchancing the efficiency of upgrading the skill level of airmen.

Cooper and Roll (1974) addressed the interchangeability of capital and labor in the production of defense. The authors desired a more efficient allocation of resources in the military sector. They suggested that the Department of Defense (DOD), by not putting the necessary effort into including costs in early planning, was penny-wise and pound-foolish. The framework the authors used was a standard economic tool, the production function, $Q=f(K,L)$ where output (Q) is a function of capital (K) and labor (L). They then pointed out several standard observations about the capital-labor ratio, the impact of technological innovation, and the implications of changes in payments to capital and labor. The result was a simple recommended approach to the problem of resource allocation of DOD.

However, the authors overlooked a pertinent side issue which confounded the analytical process: investment in humans. Such investment is actually a capital expense, but it appeared in their analysis only as a personnel (labor) cost. This factor, left unconsidered, leads to a higher real capital-labor ratio than the state of the economy actually warrants.

In addition to the human capital aspect, there was another problem in the analysis. A simpler method of arriving at an optimal resource allocation was to adjust the capital-labor ratio (i.e., adjust additional spending on each factor) until the marginal productivity of the expenditure for each was equal. Following this procedure, with increasing wage rates, investment in capital may be made and labor quantities may be cut, until the ratio of the marginal productivity of capital to the marginal productivity of labor is equal to the ratio of their prices. This, in turn, implies that the contribution to output of the last dollar expended on each factor equals the total derivative of output with respect to cost. The result of this approach, however, is the same as that of Cooper and Roll: an increase in the relative cost of one factor should lead to a substitution of the relatively cheaper factor for the other at the margin. A confusing element introduced into the analysis was inflation, where the price of each factor rose. Instead the assumption should have been that the factor changing most slowly was constant, with the other factor expressed as a function of the numeraire. This would adequately adjust their relative rates, implying a shift in resource allocation, rather than using an arbitrary across-the-board adjustment in spending on each factor. This would not have changed any conclusions reached in their paper, however.

The authors included an empirical test of their approach, and demonstrated that the cost of the labor factor has risen faster than the cost of the capital factor, at least in this country over the past 15 years. The implication was that resource allocation should have shifted to a more capital-intensive orientation.

The conclusions of their paper were: (a) that a more capital-intensive allocation of resources was probably necessary then and in the future, and (b) that the nature of the budgetary process in government and in the services did not promote trade-offs between capital and labor.

Maultsby, Ellis, and Fulton (1969) defined a structure for classifying cost models. Each category was treated by describing the characteristics of its models, a method for deriving such models, and an analysis of a model from each category. The authors described the elements of cost models and defined the problem of

cost model classification as a set of questions to be addressed by their research. A classification system was chosen which was based upon function and structure of the models. The categories were called hardware, system, force structure, and special purpose. They were discussed individually and example analyses were described. The categories corresponded roughly to civilian ideas of equipment, firm, economic sector, and special purpose program (models). The hardware model presented had been developed by ARINC Research Corporation in 1967 and applied to shipboard electronic equipment. The system model (which for the DOD included initial training as an operating, rather than an investment, cost) divided costs into three phases, research and development (R&D), investment, and operations. The model specified that system costs do not become really clear until the R&D phase has reached the contract definition stage. At that point, if no further technological breakthroughs are required, good cost estimates are possible, but infrequently prepared, because of a shortage of qualified industrial engineers to prepare estimates. Uncertainty is large until all the technical advances have been made. This is because too little good historic cost data on other R&D efforts exist. During the investment phase, large elements of the total cost of a system become more definite and predictable, and with the commencement of the operations phase, all costs are known (or at least determinable).

The model chosen as representative of the system model was the tactical support aircraft cost model of the Aeronautical Systems Division. The authors found that the model conformed closely to the Rand (Novick, 1963) method of analyzing costs of R&D, investment, and operations, except in the inclusion of training costs in the operation category rather than in the investment category, and the elimination of command support operating costs.

The authors mentioned the use of time-phased system cost models and the difference between them and static models. Largely, that difference is reflected in DODI 7041 (implemented in AFR 172-2) requiring the weighing of costs and benefits of alternative investments. The authors explained the comparison of alternatives by discounting of all benefits and costs to a common time using a ten percent interest rate.

The third category discussed was the force structure category. An amalgamation of all costs involved at the highest level of decision-making, a force structure model uses system models in the same way that system models use hardware models—as the basic input. Force structure models treat existing manpower, facilities, and equipment as given and demonstrate the additional cost of a change (net change) or they compare the total costs of different asset configurations. Force structure models consider time explicitly, as do the time-phased system models, and consider items outside specific systems (e.g., mission support) in the total. In essence, the force structure model analyzes system and overhead costs in total. The example model used by the authors was the Navy Program Evaluation Procedure (NAVPEP) developed by the General Electric Corporation. Using planning factors, force structures and exogenous variables, called "throughputs," the model yielded the total cost to the Navy, with only minor omissions.

The fourth category defined by the authors was special purpose models. These were models which neither fit the other categories nor were part of other models. Examples of special purpose models were a personnel model developed for the Navy, and a maintenance cost model developed by Rand for the Air Force. The Navy model was a fairly logical framework for determining level of repair for equipment. Of the two, the maintenance model has received more attention.

III. THE GENERAL LITERATURE

This section covers several peripheral areas not included in educational cost analysis, in a broader and more superficial review. These areas relate to this study as background material. The main areas of interest are welfare theory, human capital, and joint production.

Theoretical Issues

Central to the discussion of the economics of education are two areas of economic theory, welfare and human capital. Welfare theory is pertinent because it provides a framework for considering the effects of economic externalities. Education and training produce their output largely in a form external to the "firm" which is doing the production. The firm involved here, DOD, is collective in nature, suffering from the disadvantage of producing an output, the demand for which is not subject to normal supply/demand interactions. The theory of human capital is the second area of economic theory comprising this review. Its importance is fairly obvious, as education/training is one of two major forms of investment in human capital; health is the other form.

Welfare. It has been assumed by most bodies of conventional economic theory that an individual attempts to maximize his own welfare. Within a capitalist free enterprise system, there is no welfare which does not eventually accrue to an individual. Thus, total social welfare is essentially the sum of all individual welfare. Systems, organizations, governments, etc., do not have a welfare function of and by themselves, and they are valuable only insofar as they add to the welfare of individuals.

Public Enterprise. A public enterprise is one which is collectively owned by the populace. However, the people have not directly purchased it and cannot sell it. The people's share of the enterprise is indeterminate, and the benefits they reap from it may or may not be measurable. In general, consumption of the product of an enterprise is relatively elastic, with one individual's consumption not affecting the product's availability to another, or its price. There are many exceptions to this rule, often due to the effects of congestion, as in the use of public roads. This constraint does not operate in the enterprise under discussion, the Department of Defense. Its product is defense for the entire population, and implicitly, for the individual. The consumption of defense by an individual does not affect consumption by others, and is unrelated to its cost. "Defense" has no price, so the normal equation of cost and price at the margin does not regulate its production level. This leads to problems when the question of further investment arises. Investment normally takes place when price is higher than marginal cost, at least in a competitive situation, and continues until either the cost rises to meet the demand price (by virtue of decreasing marginal returns) or the increased output forces the demand price down to the marginal cost. This adjustment process is in the very nature of the marketplace and is the essence of the "invisible hand." What happens when there is no price to determine marginal return? In reality, the problem has been solved by the political process, which is a substitute for the marketplace. The Department of Defense receives an allocation theoretically based on the public's desire as expressed through their votes. In other words, we have a primitive points rationing scheme which should work, if grossly, to allocate public resources.

If the public enterprise wishes to make an optimal investment, by definition that investment must be such that it maximizes social welfare (the combined utility for the total population). Obviously, this does not necessarily occur automatically, as there is no price mechanism at work. Because of this, some assumptions must be made about the capital rationing system. One assumption which is possible and perhaps necessary is that the good of the society is served by the good of the Department, within a budget constraint. The budget constraint operates both to allocate capital and to avoid inter-departmental comparisons of utility, essentially by declaring them solved. The problem is reduced to deciding between alternative investment possibilities within the Department. Another assumption is that of all the alternatives available to the DOD, the choices made are at least locally optimal in the mathematical sense. This might result in an approximation of a second-best solution. For investment opportunities, A, B, and C; I = Investment; U = Utility:

$$\frac{U(A)}{A} > \frac{U(B)}{B} > \frac{U(C)}{C}$$

$$A + C = B = I$$

where U(B)>U(A+C). In this case A and C will be chosen from a list ordered by marginal utility although B would be a superior choice.

In order for the DOD to make a decision between opportunities, pecuniary results must be predictable and external effects must also be taken into account. While treatments of externality usually

assume an externality imposed upon a Pareto optimal situation (Dolbear, 1967), the present situation must assume less than Pareto optimality to start. Within a large centralized organization, it would be surprising if marginal conditions were seriously considered, much less met. The only economic criterion considered is the effectiveness of the entire unit, since the budget constrains, and actually defines, total cost. There is little attempt to reduce actual annual expenditures below the budget, because any economy which would do so would be forced immediately into increasing some performance criterion. There is no attempt to equate the marginal productivities of departments, since the departments have somewhat different funding situations. A short note at this point may give the flavor of the setting; Enthoven and Rown (1961) spoke of the Department of Defense as an anomaly of sorts:

> The defense economy is more like the economy of a college student being supported by his father, than like the economy of a household trying to allocate its expenditures efficiently within a fixed set of income possibilities. The college boy may receive a set allowance to cover minimal living or operating expenses, but beyond that he must persuade his father of the value of a particular project he wants financial support for. One day he may want a new set of law books, another day a new automobile. How much he gets will depend on how much he asks for, how he plans to spend it, and also on how he has spent his money in the past. The important characteristic of his economy is that he does not attempt to allocate optimally within a fixed budget constraint. Because the typical father considers himself to be the moral guardian of his son, budget level and allocation are inseparably tied together, and it would not be rational for the son to ignore this.

In most cases, this effect has been in operation only at the highest levels of budgeting, where the real expenditures are far removed from the budgeters. In general, the DOD decision makers have tried to maximize effectiveness and ignore marginal cost-return equality. After all, the decision maker who actually forces optimality in a purely competitive situation is the individual consumer who adjusts his demand among various goods. Such atomistic adjustment can hardly be made in the case of a large public entity like the Department of Defense. Instead, the consumer's preferences have been filtered through elected officials who, in order to remain in office, have to satisfy only a majority of their constituents. It has been in response to the demands of Congress for "more defense" that the Department of Defense has increased production. It is unlikely that the expenditures are large enough to achieve a social optimum for the Department as a whole, as the situation is so far from free competition. However, economic externalities occur in this situation and must be examined.

Bator (1958) defined externalities as the relationships that exist outside the price system which cause a divergence between social and private cost-benefit calculation. Since very little of the price system has survived the bureaucratization of DOD, much of what goes into the production of defense can be treated as an externality. The technique used to evaluate expenditures in the face of significant external effects is called cost-benefit analysis. It should suffice as a definition that cost-benefit analysis is the comparison of total costs to society with returns to society, including in their entirety both monetarily measurable and montarily nonmeasurable items, and weighting for reliability and immediacy.

The concept of externality is relevant at two levels to the consideration of DOD investment. At the gross level, defense output is a large ingredient in any risk calculations pertaining to individual welfare functions. Thus, the efficiency of DOD investments is a large part of the total welfare function. The Department's investment has a great effect on the distribution of national income, and lesser matters such as the distribution of population around installations, have an effect on the real income of individuals. Both effects have remained unmeasured to a large extent. At a finer level, much of DOD's investment has been of such a nature that the real effects of the investment on society were neither defense related nor reliably measured. For instance, efforts to improve the performance of a serviceman may have side effects which have a significant impact on society, while providing tangible (financial) results for the investing agency. (This area will be further examined in the section on human capital.) The external effects could easily result in a significant alteration of the portfolio of an organization when the returns to marginal investments and proposed investment are estimated with some reasonable degree of accuracy. (Marginal investment means the investment with the lowest rate of return. It is assumed that investments are rank ordered by rate of return, and investment choice is a comparison of potential and extant projects based on yield.) Without consideration of external effects, it is possible for an investment to exist with a nominal return which is less

than the return of the worst existing case, but with a total return greater than the total return to the worst existing investment. In such a case, neglect of the external effects has a definitely negative effect on the overall quality of the investment portfolio.

Showing the external effects of an investment with a term such as r (e) (return to an economic externality) has lent a comforting, if false, sense of precision to the discussion. It gives the impression that there is some ascertainable interest rate which can be discovered when examining external effects. Except in unusual circumstances, this has been quite untrue. There is a whole range of utility loss or gain associated with most forms of externality. For example, not only is it impossible to tell whether the odor from a refinery is more harmful to individual A's welfare than to individual B's, but it is also uncertain whether the signs of the quantities are the same. Maybe the odor is an asset, in that it drives down the cost of one's dwelling and is not all that unplatable. The same could be said of a deaf person living over a bowling alley. It is often misleading to use mathematical notation without some disclaimer regarding the implied accuracy of statements so made.

Davis and Whinston (1962) categorized externalities as either economic or noneconomic in nature. They further divided economic (or "technological") externalities into "separable" and "nonseparable." Most analysis of externality has considered economic externalities, since the marginal costs of the affected products are involved with marginal returns, and MR = MC = price. This makes the analysis somewhat more attractive, if only mathematically. If a technological externality is separable, then it has no real effect on the allocation of resources unless such an effect occurs through the forced closing of firms. If this is the case, then the firm closes because its long-run marginal cost is above its long-run marginal return (price) due to the externality; that is, the externality is nonseparable in the long run (Wellisz, 1964). A nonoptimal redistribution of resources can be avoided either by way of a unit tax on an offender transferred to the injured firm, if the externality is a function of the offender's output, or a flat tax if it is not a function of output. In this way, long-term redistributional effects can be corrected. It is not clear, however, whether this technique would lead to an optimal position. First, the tax could not be instituted free of cost, and second, there is no guarantee that a tax could be generated which would yield a position closer to an optimum than the untaxed position. Davis and Whinston (1962) point out that technological changes which affect a firm's production function would necessitate recalculation of taxes/subsidies, whereas even an imperfect market makes its adjustments automatically.

Wellisz expressed confidence that the injured party would extract as damage less than the penalty which would shut down the offending firm or force it to relocate. For example, he said, "Farmers adversely affected by smoke are better off if they receive a steady stream of compensation from the factory. . . .than they are if the factory is forced to move away" (Wellisz, 1964). By implication, the farmer's profit is greater with the externality and transfer than it is without it. Clearly this does not imply a socially optimal allocation of resources. To obtain a social optimum would require the farmer's output to be the same as without externalities; the offending firm's costs would have to include its effects on others. When the external effects to others outweigh the firm's profits (a rough measure of its value to society), the firm would close down or move. Thus, a social optimum requires that the farmer's output be the same in both cases. If the firm creating the externality is forced to shut down because it is forced to pay the farmer's damages via a tax, we would not know if the shutdown is socially optimal, unless we know whether the tax by itself would force the closing after damages are paid. Actually, a profit function might be defined such that:

$$\pi(q) = pq - C(q) - (t + dt)$$

where: q = output

p = price

t = transfer payment (tax)

dt = the administrative cost of a transfer

$C(q)$ = the variable cost at output "q"

Given that a firm is shut down because $\pi(q) < 0$ with $dt > 0$, then two situations may exist: (a) If $\pi(q) < 0$ when $dt = 0$, then the firm should be shut down. (b) If $\pi(q) > 0$ when $dt = 0$, then the effect of the tax is to drive a socially acceptable firm out of business because of the administrative cost (load) of the tax. This might be the case if the injured firm sued, and the offender had to pay damages plus court costs or a penalty. As Wellisz said, "Externalities may well be permitted to persist if the administrative action absorbs more resources than are lost through a deviation from a Pareto optimum" (Wellisz, 1964).

Human Capital. Capital is a stock of something used in the production of goods, services, or more captial. Investment is the net change in that stock over time. A dollar figure attached to either may or may not be comparable, but the qualities of the two are always different. Capital, in dollar terms, describes a state of being, a pile of objects or wealth which exists at a given instant. Investment, on the other hand, is the rate of change of that pile over time. As such, investment may be positive, negative (enlarging or curtailing manufacturing operations, for example) or zero, while capital may be positive or zero.

Capital produces nothing by itself and needs a labor input, if only in the form of instructions, to produce anything. Thus, a stock of capital plus a quantity of labor combines to form a production function in a form such as:

$$q = f(x,y) = Ax^{u}y^{1-u}$$

where A is a positive constant and $0 < u < 1$, with x and y being factors of production (i.e., capital and labor). This, the Cobb-Douglas production function, is the simpler of the two common forms of the production function. The other form, the constant elasticity of substitution (CES) function, is given by:

$$q = \ell \left\{ dx^{-u} + (1-d)y^{-u} \right\}^{1}$$

where $(t = 1/u)$; $(u > -1)$; and ℓ, d, and u are constants (Ferguson, 1969). The output, q, is a function of the two inputs, capital and labor, and a change in one of the inputs necessarily implies a change in production (output).

The stock of capital has usually been measured in money terms, as a value placed upon productive equipment. Similarly, the labor input has been measured in money terms, though it may be more informative in terms of time. Humans comprise the labor input entirely, and since the stock of capital is known, any change in the capital stock (investment) must be explained by capital input. Following this reasoning one step further, any change of product due to the labor input, and not explained by an increased number of hours worked, must be due to an improvement in the quality of the labor force. Like capital, which exhibits improvement in quality called technological change, labor can change qualitatively as well as quantitatively. One takes advantage of improving technology by investing (in capital); similarly, many economists feel that one can take advantage of potential quality change in the labor force by another type of investment, investment in "human capital."

History of Human Capital. The concept of human capital and the economic value inherent in humans goes back several centuries, at least to Sir William Petty, who evaluated laborers as a part of national wealth estimates (Kiker, 1966). He estimated the economic effects of war, migration and death.

A need for a quantitative estimation of the value of a person to his nation, to his family, and to himself arose in the insurance industry. As a result, some effort was expended to place a real cardinal value on people as individuals. Investigation was undertaken to determine the worth of people through accounting techniques. In 1853, William Farr devised what Kiker called the first truly scientific procedure for estimating the value of a human. It consisted of calculating of present value of net future earnings of an individual. Unfortunately, Farr suggested taxing individuals in the same manner used for taxing capital. This implies depreciation over time, whereas human capital typically increases over time, making Farr's tax very regressive.

Engel, in 1883, took the position that the monetary value of an individual should be his production cost. Kiker represented his formula for human value as:

$$C_{x} = c_{0} \left\{ 1 + x + \frac{kx(x+1)}{2} \right\}$$

where C_x = total cost of producing an individual (excluding interest, depreciation, and maintenance) through age x; c_0 = prenatal costs; and k = annual increase in cost (as a percent of the previous year). While it may not be appropriate to assume that the cost of producing an item is measure of the item's value, the formula may be a guide to ascertaining costs along the way. Cohn (1970) suggested changing the dependence from c_0 to c_1 (from the prenatal year to the first year after birth) and using $C_x = c_1 k^{x-1}$ or $C_x = c_1 x^k$ $(1 \leq x \leq n)$. He then used data to test his expressions against Engel's formula. Cohn's results implied that the use of c_1 in place of c_0 was preferable, but the geometric progression was not statistically superior to arithmetic progression.

Kiker reports that in the thirties, Dublin and Lotka wished to ascertain the economic value of a man to his family. They derived an equation:

$$V = \sum_{x=0}^{\infty} v^x P_x (y_x E_x - c_x)$$

where V is the value of an individual; v is the present value of $1 after x years, P is the probability of living to age x, y is yearly earnings, E is employment among people of age x, and c is the cost of living (maintenance) for a year at age x. They modified their formula to find the value at a particular age, a,

$$V_s = (P_0/P_a) \left\{ \sum_{x=a}^{\infty} v^{x-a} P_x (y_x E_x - c_x) \right\},$$

and used $C_a = V_a - V_0/P_a v_a$ to estimate the cost of producing an individual up to age a (Kiker, 1966).

Recent Treatments. Schultz (1960, 1961) utilized the concept of human capital to analyze investment in education. The concept of human capital and investment appears to have been generally incorporated into the structure of economics. Attributing much of the growth of U.S. output to something besides changes in the capital-labor ratio, Arrow (1962) surmised that something besides time should be used as an explanatory variable. He stated that trend projections "are not policy variables" (p. 155) and suggested that there was some relationship between production and knowledge. Quoting Lundberg's study of the Horndal iron works, where productivity grew at 2 percent per annum despite constant capital over a period of 15 years, Arrow advanced the hypothesis that "technical change in gneral can be ascribed to experience. The very activity of production gives rise to problems for which favorable responses are selected over time" (p. 156). He created a mathematical model in which learning took place as a by-product of ordinary production, and was embodied in the capital goods used in production. The model ignored education and research, a point mentioned in his concluding remarks.

Miscellaneous Theoretical Points

Joint Production. If a firm produces two or more outputs, usually in varying proportions, with one production process, then the products are called joint products. An example of such a process is the production of beef and leather. The slaughtering of a steer produces a certain amount of meat and a certain amount of leather. The ratio of these two products varies according to the roundness of the animal, and might be changed somewhat to fit prevailing prices by feeding or starving the animal. There is no way to produce a given quantity of one product without a certain amount of the other. In terms of the production function in which we are currently interested–producing a military operation while at the same time producing trained individuals – some potential operational work is foregone in the process of providing instruction or experience. Repetition of a task which is only needed once, in order to provide training for an individual, is such a trade off. The practice could be sacrificed; however, the first task is operational and therefore could not be eliminated. In this instance, training and the accomplishment of a portion of the mission are joint products at the "bare bones" level of the production function; neither would be traded for more of the other under most circumstances. During times of war, this sort of training has occasionally been

the only type available. For example, when experienced fighter pilots were lost or rotated out of combat, inexperienced ones would replace them in a "sink or swim" situation. This particular substitution is expensive, although it reduces the cost of on-the-job training and increases the amount of mission output, it leads to a rather rapid depreciation of human capital. (While this situation is occasionally required by circumstances, it is avoided where possible.)

Henderson and Quandt's analysis (1958) of joint products seems to be the most succinct. Given an input, X, and joint outputs Q_1 and Q_2, there is an implicit production function: $H(q_1, q_2, x) = 0$, where q_1, q_2, and x are quantities of Q_1, Q_2 and X. Solving for the input gives $x = h(q_1, q_2)$, where the cost of production of the outputs is given in terms of X.

If X is fixed, then there is a "product transformation curve" $x_0 = H(q_1, q_2)$ which gives alternate combinations of Q_1 and Q_2 which can be produced from x_0. There is a rate at which foregone Q_1 can be transformed into additonal Q_2; it is the negative of the slope of the transformation curve, or $-dq_1/dq_2$. Taking the total differential of the explicit production function, $X = h(q_1, q_2)$, gives $dx = h_1 + h_2\, dq_2$. Since X is unchanged along any one transformation curve (input is fixed at some value of x), $dx = 0$.

$$h_1 dq_1 + h_2 dq_2 = 0$$
$$h_1 dq_1 = -h_2 dq_2$$
$$h_1/h_2 = -dq_2/dq_1$$

Thus, the rate of product transformation is equal to the ratio of the marginal cost of q_1 to the marginal cost of q_2 (both in terms x) at that point.

Optimization behavior implies that one minimizes the input to achieve a desired revenue from the two outputs. In most operational settings this implies that:

1. The "revenue" desired is the sum of the two outputs;

2. the ratio of the two outputs yields the rate of product transformation, which is itself a negative inverse of the price ratio;

3. the optimization occurs when the transformation curve (and the input x) is tangent to the isorevenue (fixed revenue) line;

4. this gives minimum X with the desired ratio of the two outputs.

In an operational sense, strictly mathematical analysis rests on assumptions about the total input (x) available, minima in either or both of the outputs, or, when there is no certain way to determine demands for the products, marginal revenue figures which must come from management. This is often the case with bureaucratic and governmental functions which do not deal with physical products. This means that management must make some assumptions, and management is almost certain to make more useful assumptions when it understands their importance. Intuition alone is insufficient in a complex society.

Time. Time is a nonrenewable resource which is often misunderstood, misused, or wasted. It will be considered at it relates to interest rates and to its use in queuing.

An interest rate is an important variable in any economic calculation. It is a derivative—the rate of change of principle with respect to time. Since an interest rate is a derivative, it really is not a controllable entity, and is more of a parameter which is given by a situation. That an interest rate exists implies that an item available at different times is a different item, and that its value is different also. This leads to the idea of present value. The only way to compare items of known cost at different times is to adjust the costs to a comparable time period.

Adjusting to the present period is a common technique and is often referred to as discounting, because the items are usually in the future, and their values must be discounted due to their unavailability. The present value of a future amount, A, is:

$$P = A / (1 + r/q)^{nq} \quad \text{or} \quad P = A \times (1 + r/q)^{-nq}$$

With continuous discounting (i.e., $q = \infty$) the formula becomes:

$$P = Ae^{rt} \qquad \text{where } t = \text{the number of years.}$$

The opportunity costs associated with the use of time for a given activity determine its value to an individual. One of the largest items involved in the cost of schooling or training is the time of the students and what their time is worth in alternative uses. For an organization which pays students to go to school at the same rate at which they are paid to work, the opportunity cost is the value of the output of the unschooled person for the length of time he is in school. Wolf (1973) suggested that time spent learning may not be totally unproductive in an economic sense. On-the-job experience could turn a 40-hour week into 30 hours worth of physical product and the equivalent of 25 hours of instruction, essentially a 55-hour week for the price of a 40-hour week. This he called "double duty time" through joint production. Wolf remarked that it is efficient for several reasons, inlcuding the enhancement of earnings of students in apprenticeship programs rather than schools, and the market-affecting fact that scales of remuneration to apprentices may be good guides to their later (journeyman) remuneration, hence the price signals work more immediately than signals several years removed. In addition, the economic value of the 30 hours of productive work done implies that in every four years, three years of production is done, and one year is lost to training. However, at the 25-hour rate mentioned previously, it takes only 1.6 years to yield a year of training, and four years give 2.5 years of full-time training. If the apprentice who becomes a journeyman on the job does as good a job as the person who attends a vocational school, then a breakeven point between apprenticeship and technical school would be given by $T_a (1 - R) - T_j = 0$, where T_a is the number of time units as an apprentice, R is the value of an apprentice relative to that of a journeyman, and T_j is the number of time units required to train a journeyman at a vocational training school. If the quantity on the left side of the equation is negative, then an apprenticeship program is economically superior; if it is positive, then a full-time vocational training program is superior. Of course, this simplistic formulation is marginal, ignoring fixed costs involved in a school, and entirely ignoring instructor costs.

Queuing results when an item is priced below its competitive equilibrium. Since demand at that price would more than just clear the market, a line forms and time spent waiting becomes a substitute for a price increase. Queuing raises the real price of goods while leaving the nominal price unchanged. Lines at gas stations during a price freeze are a recent example of such a situation. In a military technical school, if a number of students are idle while awaiting the start of new classes, then queuing is increasing the real price (cost) of training. Queuing must therefore be considered in analyses of this type of situation.

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Carpenter, M.B. Analysis of educational programs. Rand P-4576. March 1971. The use of planning-programming-budgeting systems to analyze education programs is described. PPBS is a current technique for avoiding the difficulties of cost-benefit analysis. The problem of assessing the effectiveness of education systems and programs is a thorny one for which solutions are needed, but not forthcoming. There does not seem to be any prospect for using PPBS to improve the situation because the basic problem—assessing effectiveness—is not solved. However, PPBS may be a useful formatting device for placing things in perspective for analysis.

Carpenter, M.B. Maintaining efficient training programs for Air Force specialities. Rand R-427-PR. September 1970. See text.

Carpenter, M.B. Program budgeting as a way to focus on objectives in education. Rand P-4162. September 1969. A precursor of PPBS, program budgeting provided a logical framework within which studies could be done. Carpenter discussed the use of program budgeting as a tool for the analysis of educational programs. When resource allocation was done, there was a need for comparing alternatives, and PPBS and program budgeting merely provided a way of focusing on costs in a different manner. This paper suggested that when each objective is not being met, then investments have to be made across the board, rather than concentrated on fewer than all objectives. This assumed that the solution to the problem was the same when the investment was incremental as it would be if the investment were made from scratch.

Carpenter, M.B., & Haggart, S.A. Analysis of educational programs within a program budgeting system. Rand P-4195. September 1969. In this exposition of the program budgeting technique, a most important element of the use of cost-effectiveness in decision making was brought out: cost may not be minimized at the same time that effectiveness is maximized. The paper explained the steps in analysis from the definition of program objectives to the measurement of effectiveness and then provided a case study using fixed cost (variable effectiveness). The case study was a most effective

tool for exposition and provided a better description of the analytical technique than a straight description without example.

Constant, D.L. From MIS to MBC: An investigation into why one corporation eliminated its computer-based management information systems. AD-770 574. AFIT M.S. Thesis, October 1973. The experiences of the Aerojet General Corporation which led to the abandonment of its automated management information system.

Cooper, R.V.L. Defense manpower issues: Testimony before the Defense Manpower Commission. Rand P-5364. January 1975. Cooper commented on the status of the All Volunteer Force and reported that the Air Force is doing very well.

Correa, H. The economics of human resources. Amsterdam: North-Holland, 1967. This work was one of the very early attempts to define a theoretical background with which to consider the effects of factors, such as health and migration, which affect human beings as members of an economy. The emphasis was on these factors operating in a developing country, and the book is part of the literature of economic development.

Cox, J.A. Application of a method of evaluating training. Journal of Applied Psychology, 1964, 48(2). The results of applying a formula for the evaluation of training to specific data gathered from the Army are reported. The formula for this comparison was $g = n\Sigma(P_x - P_c)R - n(C_x - C_c)$ where g = dollar gain of one training program over another; n = number of persons studied; P_x = proportion of students in group x reaching criterion; R = the value of a trained man; and C_x = the cost of training program x.

Enns, J.H. The effect of the variable reenlistment bonus on reenlistment rates: Empirical results for FY 1971. Rand R-1502-ARPA. June 1975. Enns discussed a new model of the reenlistment rate (second term pay, personal attributes, civilian earnings attributable to military experience), with second term pay disaggregated into bonus, proficiency pay, and regular military pay. The results of the empirical work were: (1) variable reenlistment bonus (VRB) has a very significant influence on reenlistment rates; (2) VRB is most effective when paid in a lump sum; (3) there were no differences in the effect of VRB between the military services; and (4) Air Force and Army show that in cases in which the enlistee has a high level of education, there is less VRB effect.

Fields, D.S. Cost/effectiveness analysis: Its tasks and their interrelation. Operations Research, May-June 1966, 14(3). A general description of cost/effectiveness analysis, using as an example the analysis of a communications system in the context of possible nuclear war.

Fields, G.S., & Hosek, J.R. Human investment decisions, labor market choice, and unemployment. Rand P-5144. November 1973. The authors described a model of human investment in which the pure analysis of Becker and others was subjected to real constraints such as choice of geographic labor market, marketable skills, and job search strategy. The prime cause for this refinement is the presence of the possibility of degrees of unemployment, which varies according to the factors mentioned.

Fiorello, M.R. Getting "real" data for life cycle cost. Rand P-5345. January 1975. Problems with life cycle costing data include: (1) many data system products from different data bases; (2) different nomenclatures across data bases; (3) data quality and completeness; and (4) only 70 percent of ownership costs are known explicitly. Some improvements were suggested.

Fisher, G.H. Cost considerations in systems analysis. Rand R-490-ASD. December 1970. This is a report on the cost aspects of systems analysis, in which Fisher intentionally did not treat the other side of the systems analysis coin—effectiveness. Included are chapters on systems analysis in general, economic issues, military costs analysis, inputs to the equation, cost estimating relationships, cost models, and special topics, including uncertainty and time. Three examples of systems analyses conclude the report.

Fisher, G.H. What is resource analysis? Rand P-4705. September 1971. Resource analysis is cost/benefit analysis with one measure of costs or benefits: economic resources. The difference between other analyses and this is the emphasis on collecting all economic cost rather than in collecting only budgetary costs. In this sense, the analysis might be thought to parellel cost/benefit and economic analysis quite well.

Fisher, G.H., and the staff of the Rand Cost Analysis Department. Costing methods. In E.S. Quade (Ed.), Analysis for military decisions. Rand R-387-PR, November 1964. Military cost analysis, from the weapon system level to the force structure level. Cost sensitivity analysis and analytical results are presented in a manner which facilitates understanding of military cost analysis.

Gay, R.M. Estimating the cost of on-the-job training in military occupations: A methodology and pilot study. Rand R-1351–ARPA. April 1, 1974. Gay (1974) defined OJT and pointed out that the rising cost of personnel had increased the emphasis placed on the cost of OJT and had affected all other manpower decisions. Among those decisions he included (1) the capital-labor ratio; (2) the composition of the force, i.e. the balance between experienced and inexperienced personnel; (3) the training strategy (resident schools vs OJT); and (4) the assignment of personnel to career fields. Gay attempted to develop a methodology for the cost analysis of OJT. As bases for his approach, he reviewed previous military and civilian studies in the field and conducted a pilot study consisting of a survey of 36 men in a 700-man squadron. He discussed the statistical relationships among the independent variables in a wide-ranging manner and regressed demographic variables on cost. The ultimate value of the study lay in its pioneering effort.

Gay, R.M., & Nelson, G.R. Cost and efficiency in military specialty training. Rand P-5160. January 1974. An attempt to formulate a procedure for estimating the cost of on-the-job training, based on a survey done in one Air Force specialty. The usual framework for valuing investment was used, with training cost and the ultimate value of the trained individual as the measures of costs and revenues. There were some problems with the formulation, however. First, the authors stated that a firm will invest if the resulting income stream (discounted) is greater than the discounted investment. That is not altogether true, because organizations seek to maximize profits, rather than merely seeking to obtain a positive profit. As applied to the cost of OJT, this means not only that training must break even or pay off, but also that it must be better than the alternatives–no training and other means of training. Second, the authors' evaluation of the military training situation as it actually exists may be wrong. They stated that Air Force costs are most easily regarded as being comprised of direct outlays, pay/allowances of trainees, and the cost of OJT (wage–productivity). Their formula is:

$$\text{Cost} = D + P + (P - 0),$$

where D = direct outlays, P = pay/allowances, and 0 = output (productivity). The formula reduces to:

$$\text{Cost} = 2P + D - 0,$$

which counts pay twice. A more accurate formulation might be:

$$\text{Cost} = D + P - 0,$$

but this still mixes the cost and return sides of the "profit" picture. The error is in the assumption that the trainee will have a substantial negative effect on the productivity of the organization. (His wage may affect the total picture, but that is not the issue). It is more likely that the trainee will have a zero impact until he starts being productive, since it is unlikely that a supervisor with a mission which is paramount would take time to train a person until after that mission has been accomplished. The authors did obtain some useful information with a survey done in a pilot study. The information was in the form of military supervisors' subjective opinions as to the amount of time a person is on the job before his output equals his pay, and the amount of time between his arriving on station until his productivity equals the productivity lost by those who instruct him. It might be said that a survey respondent would answer this question with an answer to the real question, "When does a person begin to be more productive than the loss of productivity of those instructing him?" That information is useful to those using a slightly different strategy, assuming a linear function describing the output of the person over and above the output which would occur were he not assigned to the unit. It seems rational to assume that the person starts with a value of zero, finishes his training with a value equal to his pay and allowances, and reaches that point in a linear fashion.

Gillinsky, V. How shall we employ the technically trained? Rand P-4574. February 1971. This paper covers only those trained at the college level.

Goetz, C.J., & Buchanan, J. External diseconomies in competitive supply. American Economic Review, December 1971, 61(5). Treatments of the nonoptimality of competition with external diseconomies are seen as incomplete, ignoring production efficiency while focusing solely on exchange inefficiency. The authors insisted that policy prescriptions are hopeless in such circumstances: "When the precise way in which externalities enter the competitive process is clarified, the deficiencies in the standard corrective prescriptions such as Pigovian tax schemes become evident."

Greenberg, D.H. Employers and manpower training programs: data collection and analysis. Rand RM-5740-OEO. October 1968. Four manpower training programs in the Los Angeles area are described and compared. As a prime goal of his research, Greenberg explored the relative merit of the company approach to followup of program graduates. One of the programs concerned was OJT. Greenberg found that the return to the graduates was greater, at least in terms of wages received, for graduates of OJT programs than for graduates of the other programs, which were normal vocational training programs.

Haggart, S.A. Program cost analysis in education planning. Rand P-4744. December 1971. Haggart discussed the concept of cost analysis in education and developed a model for comparing the cost effects of alternative programs. There was special emphasis on the common use of numbers from cost studies with the reminder that most studies produced results which were not strictly comparable, though each may be accurate. The model assumed that existing facilities were sunk costs for each alternative, and that common factors had common prices, so that system costs may be compared.

Haggstrom, G.W. The foundations of probability and mathematical statistics. Rand P-5394. March 1974. Taken from the notes of a lecturer in a Rand Graduate Institute course, this paper covered probability models, random variables, expectation and variance, joint distributions, conditioning, correlation, sampling theory, and parameter estimation.

Haggstrom, G.M. The pitfalls of manpower experimentation. Rand P-5449. April 1975. An illustration of how to conduct small-scale pre-initiation field tests of new programs in the manpower area. The paper dealt with DoD tests of the effects of changes in enlistment periods on recruitment statistics, and gave examples of how to get reliable results.

Hansen, W.L., & Weisbrod, B.A. Economics of the military draft. Quarterly Journal of Economics, August 1967, 81(3). The effects of the U.S. draft on resource allocation and distribution—the gross national product—are discussed, including the implicit income tax on servicemen, which is the result of being forced to work for less than the market wage rate, and the loss of real output which results from non-market resource allocation. While no judgments are made, it is noted that such factors must receive explicit consideration when conscription is under consideration.

Heuston, M.C., & Ogawa, G. Observations on the theoretical basis of cost-effectiveness. Operations Research, March/April 1966, 14(2). A general discussion of cost/effectiveness analysis, in which the authors note that there are several common elements in almost all analyses, among them: Problem definition, development of appropriate arrays, definition of alternatives, development of a cost model, development of an effectivenss model, and final sysnthesis.

Hirsch, A., & Segelhorst, E.W. Incremental income benefits of public education. Review of Economics and Statistics, November 1965, 47(4). Using the technique of discounting the flow of expenditures and returns, Hirsch and Segelhorst examined the effects of schooling on future income. This differs from the technique of calculating the internal rate of return to investments in human capital.

Hoehn, W.E. Economic analysis in governmental decisionmaking. Rand P-4222. October 1969. This paper, in which Hoehn discussed the various components of economic analysis, was presented at a 1969 symposium on financial management. Among the components were the use of interest rates, the

determination of economic lifetime, the identification of alternatives, the asssessment of nonqualifiable factors, the handling of risk and uncertainty, and the identification of important parameters. The use of economic analysis on proposed dams on the Colorado River was covered. He concluded that better analyses can improve the competence of decision making but cannot relieve the burden of making a choice among alternatives.

Hoenack, S.A. The efficient allocation of subsidies to college students. American Economic Review, June 1971, 61(3). The subject is the structure of tuition charges that will result in the proper enrollment and representation of students from various income groups, while holding outside subsidy at the present rate. Hoenack used the University of California for data, and found that since all students paid less than the cost of their education, adjusting the amount of implicit subsidy will give all the adjustment range necessary and an explicit tax is not necessary.

Jones, C.R. A model of a systems analysis study. Report No. NPS55JS9071A, AD-695 427. US Naval Post graduate school, July 1969. This report described the geometry of cost-benefit decision making.

Kahn, H., & Mann, I. Techniques of systems analysis. Rand RM-1829-1-PR. June 1957. This is part one of three parts of a proposed book on military planning under uncertainty. Various techniques of systems analysis are discussed. Part three is called "Ten Common Pitfalls" and is noted below. The authors drew on the collected works of several Rand lecturers on system analysis. The paper was aimed at the military analyst in many respects, with sections on design of the defense, design of the offense, and the two-sided war. However, the concluding section titled "Evaluation and Criticism" contained many observations on analysis which have survived very well the two decades since publication. An example is that "One can legitimately recommend doing (basic research) on very flimsy evidence. That is, one shouldn't have to show that the research being recommended is likely to be useful, but only that there is a chance that it may be useful" (p. 134). The authors stated that development should also be undertaken on projects less than 100 percent certain of success on grounds that even when procurement is not indicated for a system studied, the lead time for procurement is considerably shortened if the world situation changes so as to make the system more desirable. This section implies that research that leads nowhere is useful, because it eliminates dead ends.

Kahn, H., & Mann, I. Ten common pitfalls. Rand RM-1937. July 17, 1957. In a very amusing work, the authors discussed common errors of systems analysts ranging from over-dependence on models to the introduction of a mistake of mathematics or assumption. The paper was written informally as the draft of a chapter in a later book.

Massell, A.P. An imputation method for estimating civilian opportunities available to military enlisted men. Rand P-1565-ARPA. July 1975. Veterans' occupational experiences may give an upward bias to estimates of potential civilian returns facing enlisted people.

Massell, A.P., & Nelson, G.R. The estimation of training premiums for U.S. military personnel. Rand P-5250. June 1974. Massell and Nelson dealt with the value of military training to servicemen leaving the service. The training premiums mentioned in the title refer to the addition to potential civilian income attributable to the serviceman's training. The paper was a preliminary effort to empirically discover the value to a person of what is, in essence, the Department of Defense's investment in him. Statistics used were from surveys of servicemen separated in 1969 and from military records associated with survey respondents. Infantrymen were used as a control group, since there is no good civilian equivalent to combat arms. This work falls into the general category of analysis of the value to the recipient of human capital investment. Inasmuch as that value is measured in terms of money, and that money is the wage rate, the value to the employer of the additional productivity must at least equal the "premium" he pays, or he wouldn't pay it. Therefore, the marginal product of the training is at least equal to the wage differential, and any surplus is a return to the investor's investment in training, with the government as the investor in this case.

Maultsby, W.F., Ellis, R.S., & Fulton, D.N. A classification and evaluation of current cost models. SLSR-7-69, AD-863 844. Master's thesis for the School of Systems and Logistics, AFIT, Air University. August 1969. See text.

McCall, J., & Wallace, N. Training and retention of Air Force airmen: An economic analysis. Rand RM-5384-PR. August 1967. An analysis of the problem of retaining generally trained electronics specialists in the Air Force. McCall and Wallace see it as a simple supply and demand problem, with the pay of the airmen too low to keep them in the service. According to the analysis, a shift from proficiency pay to a reenlistment bonus should make a large difference, since the civilian alternatives faced by the airmen do not pay very much better than the military.

Mincer, J. The distribution of labor incomes: A survey (with special reference to the human capital approach). Journal of Economic Literature, March 1970, 8(1). The article reviewed the literature on distribution of income in which the traditional approach was compared with the human capital approach. Econometric attempts to determine the effects of investments in human capital were reviewed and interpreted, and general issues in the area were discussed.

Mincer, J. On-the-job training: Costs, returns, and some implications. Journal of Political Economy, October 1962, 70. See text.

Morgan, J., & David, M. Education and income. Quarterly Journal of Economics, August 1963, 77(3). When the effects of education on income were studied, objections to the use of average annual earnings of groups by age and education were not terribly important to the results. An interesting observation was that some of the effects of further education on earnings were hidden by those educated who take their additional income in the form of increased leisure. There is also some impact on employment statistics by virtue of the same phenomenon.

Nelson, R.R., & Phelps, E.S. Investment in humans, technological diffusion and economic growth. Rand P-3295. December 1965. In a paper presented at the 1965 meeting of the American Economic Association, the authors hypothesized that the more educated a manager is, the more likely he is to try new techniques, and thus the greater the education level of management, the greater will be the rate of what is called technological diffusion. Preliminary evidence for this hypothesis was taken from the example of American agriculture. It appeared that the more dynamic the technological adaptation of an economy, the greater should be the rate of investment in human capital.

Pardee, F.S. Weapon system cost sensitivity analysis as an aid in determining economic resource impact. Rand P-2021, June 15, 1969. In an early Rand paper on cost analysis, Pardee discussed the technique called "sensitivity analysis" as a tool for evaluating proposed weapon systems before their design and production. Cost sensitivity analysis is the singling out, from the myriad of cost elements, of those elements which have the greatest impact on system costs for each percentage of change in factor input. Often factors which loom large in the total cost of a system do not vary greatly as paramters change, while less noticeable factors may fluctuate wildly with incremental changes in system performance characteristics. Sensitivity analysis explicitly addresses the issue of differing cost effects for different elements, and of examining the possible effects of those differences on the final results. Pardee emphasized that cost sensitivity analysis is only a part of a larger study, and that its results should not be evaluated in isolation.

Perlman, R. On-the-job training in Milwaukee–Nature, extent, and relationship to vocational education. ERIC ED-034-161. Center for Studies in Vocational and Technical Education, Industrial Relations Research Institute, University of Wisconsin, June 1969.

Petruschell, R.L., & Chester, J.M. Total system cost analysis–Part I. Rand RM-3069-PR. January 1963. Several aspects of cost analysis are treated in a memorandum designed to be part of an Air Force Institute of Technology course in cost estimating concepts and techniques. The sections were: the nature of total system cost analysis, system description, personnel estimating, and estimating mission equipment. While the topics were oriented to military cost analysis, the points made were general enough to have relevance for all cost analysis.

Pincus, J. Policy studies at Rand: Education and human resources Rand P-4721. October 1971. Pincus reviewed the work underway at Rand in the area of education research, with a short word about future directions as of 1971. The entire program concerned the evaluation of the costs and effectiveness of the public school system, with no treatment of general investments in human capital, i.e., vocational training. The overall conclusion was rather pessimistic; Pincus reported that no effective conventional or innovative treatment of public school students was being provided, given the social backgrounds which existed. The implication is that what goes on in the classroom has little impact on the students.

Quade, E.S. (Ed.). Analysis for military decisions. Rand R-387-PR. November 1964. A collection of essays on the topic of systems analysis, particularly those presented at Rand courses during the fifties. The courses were offered to decision makers rather than analysts, and tried to give an appreciation of the subject. The content was aimed at teaching the interpretation, rather than the performance, of analyses. This collection was reviewed by F.M. Scherer in the December 1965 issue of the *American Economic Review* (see below).

Quade, E.S. Analysis for public policy decisions. Rand P-4863. July 1972. In a paper presented at a seminar on policies and systems analysis in 1972, the author discussed the increasing acceptance of quantitative analysis by politicians and called for the future improvement of the accuracy of systems analysis techniques.

Quade, E.S. Cost-effectiveness: An appreciation. Rand P-3248. October 1965. A definition and exploration of cost-effectiveness analysis, giving its limitations and its strengths. Quade believed that there was room for further use of the method, even in the Department of Defense, where its use was usually greater than elsewhere.

Quade, E.S. Cost-effectiveness: An introduction and overview. Rand P-3134. May 1965. This paper seems to be a draft of the paper mentioned above, as there is little difference between the two.

Quade, E.S. Pitfalls in military systems analysis. Rand P-2676. November 1962. In a paper presented at a symposium in 1962, Quade discussed systems analysis as an approach, rather than a method, to look at complex problems of choice under uncertainty. His subject was two classes of error found in systems studies–blunders and fallacies. He found that blunders will continue to occur, but that there was some hope for eradication of fallacies in analyses.

Quade, E.S. Some comments on cost-effectiveness. Rand P-3091. March 1965. According to Quade, the difference between systems analysis and cost-effectiveness is one of emphasis. Systems analysis is concerned with assisting decision makers on matters of policy, while cost-effectiveness analysis is more specifically concerned with the comparison of alternatives from the point of view of cost and effectiveness. Quade mentioned two specific limitations of analyses–the necessary incompleteness of each analysis and the vagueness of effectiveness measures. He discussed two pitfalls mentioned in his 1962 paper–the cherished belief and overeliance on models to make decisions. The main conclusion is that the design of studies and analyses, the formulation of the basic questions which need to be asked, is more important than the particular techniques used.

Quade, E.S. Systems analysis techniques for planning-programming-budgeting. Rand P-3322. March 1965. This paper offers an explanation of systems analysis and a proposal for its use in much wider applications than weapon system choice. System analysis offers a framework broad enough for most social issues within government.

Quade, E.S. The systems approach and public policy. Rand P-4053. March 1969. In this paper, a Rand spokesman for systems analysis presented his views of the place systems studies occupy in the world, and of the major attributes of such studies. He reported that such analyses have gained acceptance in industry and government decision making, but that advances must be made in further making systems studies useful and acceptable. On the part of decision makers, more use must be made of the capabilities which exist, and more support must be given to those who implement studies. Quade discussed modeling as it is generally practiced in systems studies and suggested that models be

extended beyond mere numerical representation to include verbal descriptions of the way things work. Such models, according to the author, are equally useful so long as they maintain their predictive abilities. Quade's definition of a model is "any device that provides a means to predict and compare the outcomes of alternative actions." An example of such an extended model is the Delphi technique developed at Rand for eliciting and refining expert opinion through anonymity in what would otherwise be an open discussion.

Rostker, B. The Air Reserve forces and the all-volunteer force: A statement before the Defense Manpower Commission. Rand P-5359. January 1975. Rostker points out that non-prior service airmen's pay increased relative to that of the career forces, but there was no change in the utilization patterns of these two groups (p. 4). The strength of regular forces was satisfactory, but that of the reserves was falling.

Rostker, B. An econometric model for the evaluation of manpower programs. Rand P-4944-1. October 1973. Rostker suggested using a standard national control group for the evaluation of manpower programs with the aid of a simple econometric model. This technique was used to evaluate the performance of employment counselors in California.

Scherer, F.M. Review of "Analysis for Military Decision," by E.S. Quade, American Economic Review, December 1965, 55(5). Scherer states that ". . a recurring theme (of the Quade paper) is the frequent superiority of rough, common-sense qualitative analysis over high-powered optimization techniques. . . . A second theme is the need for iteration and feedback in redefining objectives and devising new, dominant solutions. Also emphasized is the role of 'sensitivity analysis'—estimating how conclusions may be affected if uncertain parameters take on adverse values."

Schlesinger, J.R. The changing environment for systems analysis. Rand P-3287. December 1965. This paper presents four factors which have affected the performance of systems studies since the concept was developed: (1) increased political fluidity, at least in terms of the major threats which defense policy must consider; (2) a more sophisticated approach to the conduct and perils of nuclear warfare; (3) emphasis on specialized weapon systems; and (4) the rising costs of R&D. Schlesinger provided two examples for illustration and concluded with some observations on what had preceded.

Schlesinger, J.R. On relating non-technical elements to system studies. Rand P-3545. February 1967. In this paper, a future Secretary of Defense examined the role of what he called "soft" factors in systems analysis, and he laid much of the blame for policy failures on the exclusion of such factors as the political environment. As he stated, "In such an environment (that of the government bureaucracy as decision maker) the excuse that the best laid schemes of mice and men gang aft a-gley is invalid, for the neglect of the real character of the environment implies that the plans may be the worst laid." Studies of the pure resource allocation problem are a good starting point, but feasibility of implementing the resulting proposals must be of prime concern. Only in that way may "second-best" alternatives be considered, i.e., alternatives which are the best available under the circumstances. In addition, he made the point that, as Whitehead remarked, the recommendations for the real higher level decision makers may not be completely susceptible to purely numerical analysis.

Schlesinger, J.R. Systems analysis and the political process. Rand P-3464. June 1967. The use of systems analysis on public issues, and the difficulties encountered there were examined. The confusion in civilian agencies between input and output was mentioned (the concern of the Forest Service with timber rather than lumber, for instance). It is the tendency of in-house research to be so theoretically pure that it is of little use, and the possibility exists that the analysis may mask political choice as economic efficiency and therefore interfere with the decision making process.

Schweitzer, S.O. Occupational choice, high school graduation, and investment in human capital. Journal of Human Resources, Summer 1971. 6(3). According to this article, it is not always the case that high school graduation increases lifetime earnings prospects. Specifically, when the student has certain occupations in mind, "high school graduation does not appear justified on economic grounds, when

past cross-sectional earnings patterns are used to predict the future." Some of the occupations which showed a negative return to schooling in this study were electricians, drivers, barbers, and shipping and receiving clerks. Interestingly, while electricians showed a negative rate of return, the rate for painters, bricklayers and plumbers, (all closely allied fields of endeavor) were positive by a good margin. The author concluded that if those workers who wished to join trades with negative return to education were perceptive enough to see that their lifetime prospects were not enhanced by further education and therefore dropped out, the observed high rate of return to high school graduation would be somewhat the result of the self-selection of those whom it would aid.

Shishko, R. A survey of solution concepts for majority rule games. Rand P-5169. August 1970. (Revised Janaury 1974.) Shishko provides a mathematical review of the concepts of the core, bargaining sets and n-person games with side payments and transferable utility.

Smith, R.E. The opportunity cost of participating in a training program. Journal of Human Resources, Fall, 1971. 6(4). Presentation of a model, based upon the characteristics of the participants, for estimating the foregone income of participants in training programs. The model was developed for use in the context of programs under the Manpower Development and Training Act.

Strauch, R.E. A critical assessment of quantitative methods of a policy analysis tool. Rand P-5282. August 1974. The application of mathematical methods and models to the spectrum of policy problems was considered. Strauch looked at the limitations of mathematical methods at the "squishy" end of the spectrum and suggested that there was a tendency for the analyst to assume that a problem was susceptible to accurate description within his framework and proceed uncritically as though that were the case, getting "good" numerical results and accepting them as real even though the model was not a very good analogue of the real situation. He stated, "When we look for the answers to complex social, political, or behavioral problems in computer based models, therefore, we may be returning full circle–back to the shaman and the oracle, asking a magical mechanism beyond the range of human consciousness and understanding to provide us our answers." (p. 87).

Strauss, W.J. The nature and validity of operations research studies, with emphasis on force composition. Operations Research, Operations Research, September/October, 1960, 8(5). The composition and function of operations research studies as of 1960. Much of the subject of this study has been subsumed by either systems analysis or one of the several forms of economic analysis. The author assayed the value of operations research studies, and he found that although operations research cannot guarantee the best decision, it was the best method available. "In the hands of a talented analyst, it yields believable, useful results with higher reliability than any other method so far suggested."

Sumner, G.D. Sampling method: Suggestions for military cost analysis. Rand RM-5779-PR. October 1968. A general description of sampling, sample design, estimation from sample statistics, and survey procedures, primarily for the military cost analyst. The paper is basically an instruction package based on available sources which are listed in its bibliography.

Thompson, V.M., & Thompson, E.A. On the efficiency of a competitive equilibrium with education as a screening device. Rand P-5356. January 1975. The authors disagreed with earlier models which showed that there was overinvestment in the education of workers, on the basis that an implicit assumption was unrealistic. The assumption was that good school performance was communicated to prospective employers but that poor performance was not. A revision in assumptions showed a general underinvestment in the education of workers when employers use education as a substitute for specific knowledge about workers' productivities.

Weiss, L.W. Concentration and labor earnings. American Economic Review, March 1966, 56(1). The wage rates of various industries were related to the degree of monopolization in the industries. The article was not entirely relevant to OJT except that it notes the tendency of laborers to invest in their human capital at their own expense.

Weiss, Y. Investment in graduate education. American Economic Review, December 1971, 61(5). Weiss attempted to link graduate fields and degrees sought to individual potential lifetime incomes. The study was restricted to a single cross-section of 5,686 of the 242,800 members of the National Register of Scientific and Technical Personnel in 1966.

Welch, F. Human capital theory: Education, discrimination, and lifecycles. Rand P-5351. January 1975. This is a short critque of three aspects of human capital theory, with the conclusion that the theory does not address, much less explain, much of what is at issue in human capital discussions of race differences in income. The author stated, "Theories of human capital and of discrimination tend to be associated because both are parts of a comprehensive view of earnings differentials and because work by Gary Becker serves as a benchmark in each area."

Weiner, R., & Horowitz, S.A. A production function for trained recruits. Professional Paper No. 84, AD-734 858. Center for Naval Analyses, November 1971. Derivation of a production function which can be used to describe the capital and labor input into the production of trained military workers.

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☆U.S. GOVERNMENT PRINTING OFFICE 1978- 771-122/34